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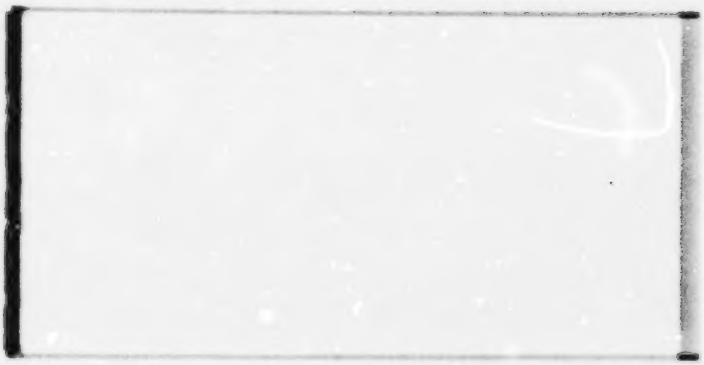

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CONDENSATION IN STRUCTURES
STATE-OF-THE-ART

Report No 84-166-K

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ABSTRACT

This state-of-the-art report presents the Ontario Hydro Research Division experience and a review of literature on condensation problems. Estimates indicate that the problems are found in less than 2% of the households in Ontario. Nonetheless, this could still be up to 60,000 households. The report highlights the types of problems in existing, thermally upgraded, electrically converted and new, tight homes in Ontario. So far there is little evidence that regular energy conserving measures cause severe condensation problems. Also, all of the condensation problems experienced by residences can be corrected. But, the potential exists for creating difficult problems when upgrading residences by improper reinsulating or by significant airsealing. Diagnostic techniques and solutions for particular problems are detailed in the report.

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To Mr. F.J. Kee
Director of Research

CONDENSATION IN STRUCTURES
STATE-OF-THE-ART

1.0 INTRODUCTION

In response to a request by the Residential Marketing Department, an investigation was undertaken to determine the extent of condensation problems in Ontario homes. This report presents the Ontario Hydro Research Division experience and a review of relevant literature published during the last few years. The report highlights the state of condensation problems in existing, thermally upgraded, electrically converted and new, tight Ontario homes. It makes recommendations on how the advisors of the Residential Energy Advisory Program and homeowners can diagnose the symptoms and reasons for problems and arrive at suitable solutions. The report is written in the form of a manual for Residential Marketing use. Additional recommendations are made for subsequent research work.

1.1 Overview

Three recent reports estimate that the percentage of the housing population in Ontario having problems is small, viz:

Scanada/1/	< 2%
Marshall et al/2/	0.7%
Ontario Hydro Research/3/	1 out of 49 Plenum Heater Field Trial Homes

The percentage of reported cases is small but the absolute number of cases may be significant, possibly 60,000 of the three million households in Ontario. The homes experiencing problems are predominantly flueless, electrically heated (see Table 1). According to Marshall et al/2/, all units inspected that had moisture problems, had indoor relative humidities well above Canadian averages. Along with the obvious moisture sources of bathing, cooking, etc., recent investigations indicate that moisture wicking through concrete basement floors is a

significant source. The majority of problems are located in the attic and ceiling because of exfiltrating (outward) leaks in these locations. Problems in thermally upgraded homes usually appear within one to two years after retrofitting. The literature and our experience strongly suggest that all of the condensation problems experienced by homes can be solved.

Homeowners can reduce excessive humidity levels and thus alleviate most condensation problems by employing the few simple steps listed below:

1.	Limit Humidity Sources: Operation of furnace mounted and portable humidifiers should be reduced or discontinued. In addition, consciously attempt to avoid lifestyle habits that unnecessarily contribute to indoor humidity eg, do not hang wet clothes indoors, limit over extended cooking time if shorter time will suffice.
2.	Dehumidify: If reducing humidity sources is not enough, household dehumidifiers can be used to limit humidity to a minimum of about 60% relative humidity (RH).
3.	Exhaust Indoor Humidity: Unvented clothes dryers should be vented outdoors. Similarly, kitchen and bathroom humidity should be exhausted directly outdoors before it spreads to the entire house. Ultimately a central controlled ventilation system may be required to control humidity levels in the entire house.

The potential exists for creating condensation problems when upgrading residences by improper reinsulating or by significant airsealing. So far there is no definitive evidence of an increase in the number of serious cases because of recent energy conserving measures/1/, but the further advance of tighter and more insulated envelopes should be monitored for any increase in problems since the potential does exist.

Houses conscientiously made airtight will require controlled ventilation. The design and installation of residential controlled ventilation systems are documented in a draft set of guidelines produced for Canadian home builders/11/. The guidelines specifically address new home construction. Retrofit installations are more difficult, but the guidelines can be used as a starting point and basic reference. The chimney left over from conversion to 100% electric heating can be a suitable exhausting vent. Additional research is required to check the practical details.

A substantial amount of building science research has been carried out. In spite of this a large gap exists between what is known and what is actually practiced. Educating contractors and homeowners is required.

Table 1 shows an estimation of the total number of problems in Ontario by house type. Table 2 lists the incidence of the various types of moisture problems. The problems labelled "siding" include buckling and peeling paint. Mould and mildew appear on interior surfaces of outside walls. Condensation problems at the attic/ceiling interface are attributed mainly to air leakage. Windows are usually the first place where condensation appears and generally a small amount of condensation is acceptable; only persistent, significant condensation is considered a problem. The right-most column of Table 2 indicates the rank of Ontario problems with respect to all of Canada.

All the items discussed in this overview are expanded upon below.

2.0 METHODS OF CONDENSATION CONTROL

2.1 Control Relative Humidity

Basically condensation appears as either visible condensation or concealed condensation. Visible condensation, sometimes referred to as surface condensation, is generally caused by high indoor humidity during periods of cold outdoor weather. It usually appears on windows, on inside surfaces of exterior walls, and in closets, and often is manifested as mould, mildew and staining. Concealed condensation found in wall cavities and the attic space is attributed to moisture from indoors transported by air leakage through cracks. Marshall et al/2/ reported that the residences they inspected that had moisture problems also had relative humidities well above Canadian averages.

Visible condensation is a warning sign. It will initially appear on windows and if excessive and persistent it indicates humidity levels are too high. Levels may vary daily and seasonally. Since the trained inspector may not witness the house in its worst condition, educating the homeowner to recognize the signs is more effective. If relative humidity levels are persistently high then the first step is to check for large regular moisture sources and try to control them. For all types of condensation problems the problems can be solved. As a basic educational resource, Appendix A lists the government publications related to residential condensation problems and is strongly recommended for distribution to homeowners, REAP personnel and contractors.

In addition to visual observation, instruments and devices can be used for diagnosing excessive relative humidity. Commercially available sling psychrometers are small (pocket size) and meant for portable field use. Household style hygro-

TABLE 1

SUMMARY OF MOISTURE PROBLEMS IN TYPES OF HOUSES IN ONTARIO/2/*

HOUSE	ESTIMATED TOTAL NUMBER OF PROBLEMS	PERCENTAGE OF PROBLEM HOUSES HAVING ELECTRIC HEATING (ie, flueless)
Single Family Detached	230	66%
Semi Detached and Attached	590	50%
Mobile, Modular	20	100%
Apartments	1010	85%
TOTAL PROBLEM CASES	1850	

TABLE 2

INCIDENCE OF VARIOUS TYPES OF MOISTURE PROBLEMS IN ONTARIO/2/**

PROBLEM	SINGLE FAMILY DETACHED HOUSES	SEMI DETACHED & ATTACHED HOUSES	NATIONAL RANK
Siding	L	NIL	lowest in Canada
Mould & Mildew	H	L	highest in Canada
Attic/Ceiling	H	H	second highest province
Windows	L	L	national average

* Marshall et al/2/ reported specifically for 276,000 NHA houses. NHA housing comply with the same Building Code as all other housing in Ontario so that the report is probably representative of the population at large.

** L: <50% of the reported cases
H: >50% of the reported cases

meters are available from hardware stores for a few dollars. They are appropriate indicators of either high or low humidity levels. Another simple and makeshift method consists of filling a tin can with ice and water. The temperature of the ice-water mixture is allowed to decrease until eventually incipient condensation appears on the exterior surface of the shiny tin can. At this point, measuring the temperature of the mixture with a thermometer gives the dew point temperature of the ambient air. Referencing the dew point temperature and the normal ambient air dry bulb temperature to a psychometric chart (see Appendix B) determines the relative humidity.

Various sophisticated instruments for humidity and moisture measurement are documented in Appendix C.

The primary method for reducing visible condensation and also concealed condensation, is intentionally lowering indoor humidity to an appropriate level. The table below, reproduced from Reference 4, recommends appropriate levels for outside temperatures ranging 15°C to -40°C.

INSIDE RELATIVE HUMIDITY FOR 21°C
WITH DOUBLE GLAZING

OUTSIDE AIR TEMPERATURE	INDOOR RELATIVE HUMIDITY LESS THAN
(°C)	%
15	85
10	70
5	60
0	55
-5	45
-10	40
-15	35
-20	30
-25	25
-30	20
-35	15
-40	5

In order to maintain relative humidity levels the first step to take is reducing the operation of the furnace-equipped humidifier or any room humidifiers. Several other common household practices which contribute to excess humidity, and practical steps to alleviate problems, are discussed in detail below, and are very clearly outlined in Reference 4, p 9-11.

The suggested humidity levels above will protect against condensation problems in the house, but, depending on the occupant's health, the risk of the common cold may become higher below 30% relative humidity/5/. Therefore, it is necessary to make the house more tolerant of the humidity levels which are optimum for humans. Alternatives to controlling excessive condensation may include adding storm windows or insulation on surfaces to elevate surface temperatures above the dew point temperature.

2.2 Control by Air Sealing

Concealed condensation is caused mainly by the transport of moist indoor air outwards through leaks in the building envelope. Condensation will become trapped inside the wall space and unnoticed until damage occurs such as peeling paint, ice inside the attic, water dripping from light fixtures, etc. There is also the potential for serious structural damage if dry rot is allowed to develop.

It has become recognized that air movement is a stronger mechanism than vapour diffusion for transporting water which contributes to hidden condensation. Calculations reported by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)/6, p 21.91/ show that 6-7 times as much water can be deposited as a result of air leakage as by vapour diffusion. Therefore, the primary defense against harmful hidden condensation must be control of humid air movement within a building structure by means of airtight construction.

The direction and rate of air flow through cracks depend on the direction and magnitude of air pressure differences created by stack effect (due to the winter temperature difference between inside and outside), wind, chimneys, fans and blowers. For electrically heated homes the midwinter pattern of pressure differences will resemble that shown in Figure 1. Wind pressures will directly act to cause air infiltration on the windward side, and exfiltration on the leeward side. The pressure acting upon the ceiling is mainly due to stack effect. Warm inside air, more buoyant than outside cold air, will rise and flow outward through cracks in the upper walls. On contacting increasingly cold surfaces and eventually those below the dew point temperature, condensation occurs and if cold enough, ice will form. Marshall et al/2/, have observed a higher incidence of the problem on second floors which is mainly attributed to air exfiltrating there.

The upward air pressure difference is counteracted or even reversed by a fossil fueled furnace exhausting much hotter flue gases and air through the chimney (Figure 2). Unless the combustion chamber is supplied by outdoor air the chimney behaves like an exhaust fan discharging a large quantity of indoor humidity. (This may have an effect on the integrity of the chimney system.)

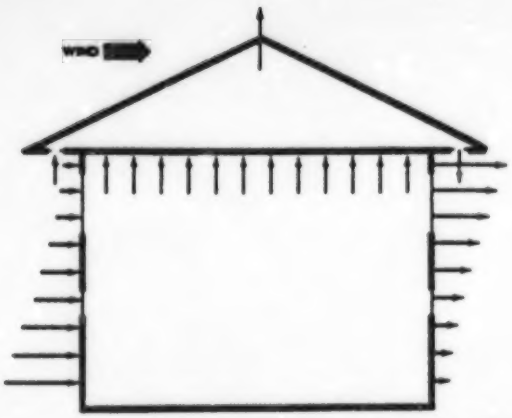


FIGURE 1

Pressure Differences in Electrically Heated Houses

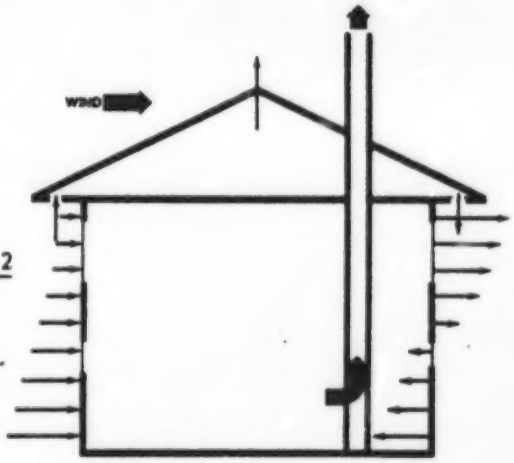


FIGURE 2

Pressure Differences in Fossil Fuel Heated Houses (Unless a Positive Supply of Air Is Brought Directly to Heating Unit)

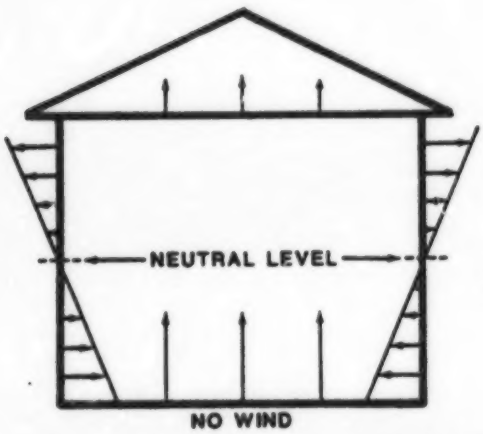


FIGURE 3

Pressure Differences Caused by Stack Effect for a Typical Structure. Arrows Point from Higher to Lower Pressure and Indicate Direction of Air Flow

FIGURES 1,2, 3 -

Source: ASHRAE, 1981 Fundamentals Handbook American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia. 1981.

The infiltration and exfiltration of air through a building envelope are associated with the pressure distribution over the building. That point in the vertical, exterior surface where the interior and exterior pressures are equal is called the Neutral Pressure Level/6/ (Figure 3). Below this point, during winter, the exterior pressure is larger than the interior, causing infiltration through the cracks. Above, the interior pressure causes exfiltration, and exfiltrating cracks are the ones where concealed condensation occurs.

Building science researchers now discriminate between vapour retarders (formerly called vapour barriers) and air barriers. Materials may be vapour permeable or air permeable, or both. A vapour retarder can be defined as a (usually) thin sheet or coating that restricts the diffusion of water vapour induced by a difference in water vapour pressure. Generally, a material that is sufficiently impermeable to be a vapour retarder would also probably stop the passage of an air current. For a vapour retarder to double as an effective air barrier it must not be torn, or installed with gaps. If torn or not sealed at joints, it will be useless as an air barrier, but will probably still act as an effective vapour retarder. The proper place for a vapour retarder is on the warm side of the insulation. Certain new wall constructions place the vapour retarder within the insulation to protect it from penetrations by wiring, plumbing etc, so that it also acts as an effective air barrier. This practice is acceptable as long as at least 2/3 of the insulation is still outside the retarder so that the dew point location is external to the retarder.

To allow for natural drying out of walls during late spring and early summer, wall construction should have a inherent "safety valve". Unquestionably, the materials in the wall cross-section will slow down water diffusion and therefore behave as a vapour retarder and inhibit natural drying. To encourage drying out, the materials on the outside surface must be more permeable than the inside materials. The worst case is to have a double vapour retarder which inevitably would trap moisture in the wall cavity. A ratio of 5 to 1 permeability for exterior side to the interior side was adopted many years ago. However, this ratio changes with different wall constructions. More recent research/7/ suggests a ratio of approximately 2 to 1.

Concealed condensation may not become evident until substantial damage has occurred. When investigating for concealed condensation problems, the upper parts of the house should be checked first since exfiltration is predominant here. Attic penetrations, attic hatches, second storey windows and electrical boxes are the most likely spots.

Certain home improvements may create conditions for a problem situation. For example, retrofitted range hoods may discharge into the attic and not directly outdoors. New aluminum soffits should be open and not blocked by the insulation in the attic.

Energy, Mines and Resources is coordinating the publication of a Handbook on Air Sealing Homes for Energy Conservation/8/ meant to be suitable for air sealing contractors. In addition, Appendix A lists homeowner publications dealing with caulking and weatherstripping.

2.3 Control by Ventilation

Inability or unwillingness to control humidity sources, or conscientiously air sealing a house will make mechanical or passive controlled ventilation necessary. A method of ducting in dry outside winter air will serve to dilute indoor humidity. (Cold winter air when raised to indoor temperatures will have a much lower relative humidity than warm inside air.) A suitable means of exhausting stale indoor air will also be required to complete the controlled exchange of inside and outside air. Controlled ventilation will provide an environment adequate for human health and comfort, maintain humidity levels to defend against building damage and will contribute to wise energy use by allowing no more ventilation than necessary.

Opening windows affords only temporary relief and causes cold draft discomfort. After the windows are closed, any persistent water vapour will increase indoor relative humidity to the original levels. What is worse, the windows may ice up and not reclose properly. Therefore, windows are not satisfactory ventilation devices in very cold weather. ASHRAE has developed standardized ventilation requirements for indoor air quality and indoor humidity control/9/. Briefly, a steady ventilation rate of 5 L/s per habitable room is required, plus, to exhaust excessive humidity, odours, etc.:

25 L/s per each bathroom, when used
50 L/s per each kitchen, when used

For simplicity, the ventilation rate is defined independent of room size. For example, for a seven room house (living room, kitchen, dining room, two bedrooms, bathroom, family room), a continuous rate of 35 L/s is specified, with extra capacity in bathrooms and kitchen for intermittent use when required. Incorporating a dehumidistat to control ventilating fans is recommended.

The attic hatch is a possible location for retrofitting a powered or passive exhaust duct/10/. This idea requires further study.

3.0 SITUATIONS PRONE TO CREATING CONDENSATION PROBLEMS

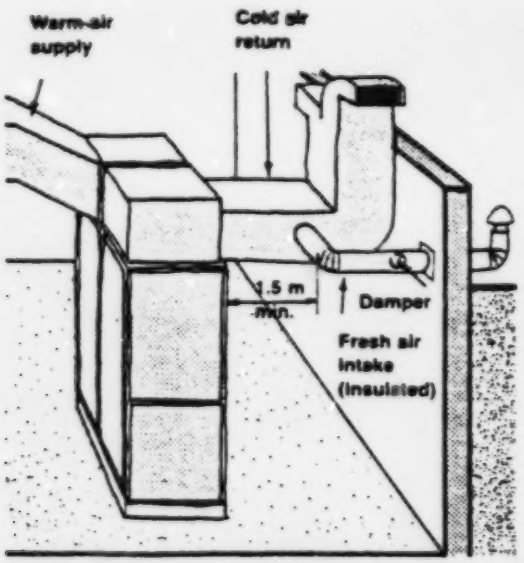
3.1 Conversions to Electric Heating

For cases of conversion from fossil fuel heating to electric heating the existing chimney is often blocked to increase the airtighness of the structure. However, the permanent blockage of the chimney in a tight house may cause serious condensation and ice at any residual penetrations, especially in the ceiling/3/. A better alternative is to only temporarily block the chimney or adapt it with a manual or humidistat controlled damper. Any incidence of moisture on the second storey should be monitored, particularly the leeward side of the house. If ice or moisture are observed behind light fixtures or at wall joints in the attic, the chimney damper should be opened more. If no significant appearance of condensation problems is seen over the first winter, permanent blockage of the chimney can be contemplated.

For electric forced air furnaces a simple system consisting of a short insulated duct, with an integral damper, can be installed to supply outside air to the furnace cold air return duct (see Figure 4 below). Baseboard heated houses may require a manually operated mechanical ventilation system/11/.

FIGURE 4

FURNACE FRESH AIR INTAKE



Source : CMHC, Condensation in the home: Where, Why and What to Do About It. Ottawa, Ontario, 1984.

3.2 Reinsulating

Reinsulating homes without first installing vapour retarders and air barriers invites condensation problems. Retrofitting additional insulation has the effect of reducing temperature on the cold side of the retrofitted insulation. Furthermore, most thermal insulations have very little resistance to air flow. The result is increased incidence of condensation, frost or ice. Problems usually become evident 1-2 years after retrofitting/1/.

3.3 New Construction

Newly constructed homes require a drying out period. Temporary measures like supplementary ventilation may be required to control humidity from drying studs, drywall and other moisture-laden construction materials. Generally, homeowners should wait until the second heating season before taking permanent measures to solve condensation problems.

Air-to-air heat exchangers are suitable mechanical ventilation systems and may be economical for new tightly constructed homes. They require very tight airsealing in order to establish balanced air flow through the heat exchanger and so give effective heat recovery. Retrofitting a heat exchanger and the necessary ductwork in existing homes can be expensive.

4.0 TYPES OF CONDENSATION PROBLEMS

4.1 Attic/Ceiling

The survey conducted by Marshall et al/2/ revealed the majority of houses with moisture problems have attic/ceiling problems and that Ontario has the second highest incidence in Canada (Table 2). Scanada Consultants/1/ discovered in another survey, that lack of integrity of the attic air barrier is a characteristic shared by both old and new houses.

The primary mechanism causing concealed condensation is air leakage. Therefore it is necessary to get control of attic leaks before insulating. Insulating will not significantly retard moisture but it will cause the attic to be colder, thus increasing condensation. Just ventilating the attic and not sealing may exacerbate problems in that ventilation may draw

even more air and thus moisture through the ceiling into the attic. Extra energy will also be lost by ceiling air leakage.

Weatherstripping and airsealing the attic hatch are essential, otherwise moisture and ice could accumulate in the vicinity of the hatch/3/. The first winter after upgrading attic insulation, the homeowner should inspect the attic and check for signs of moisture and ice such as rusting nails, staining or discolouration of wood and signs of water dripping on the top of the insulation. A similar inspection should also be made during the second winter.

Appendix D(i) outlines a checklist for moisture damage in the attic.

4.2 Walls

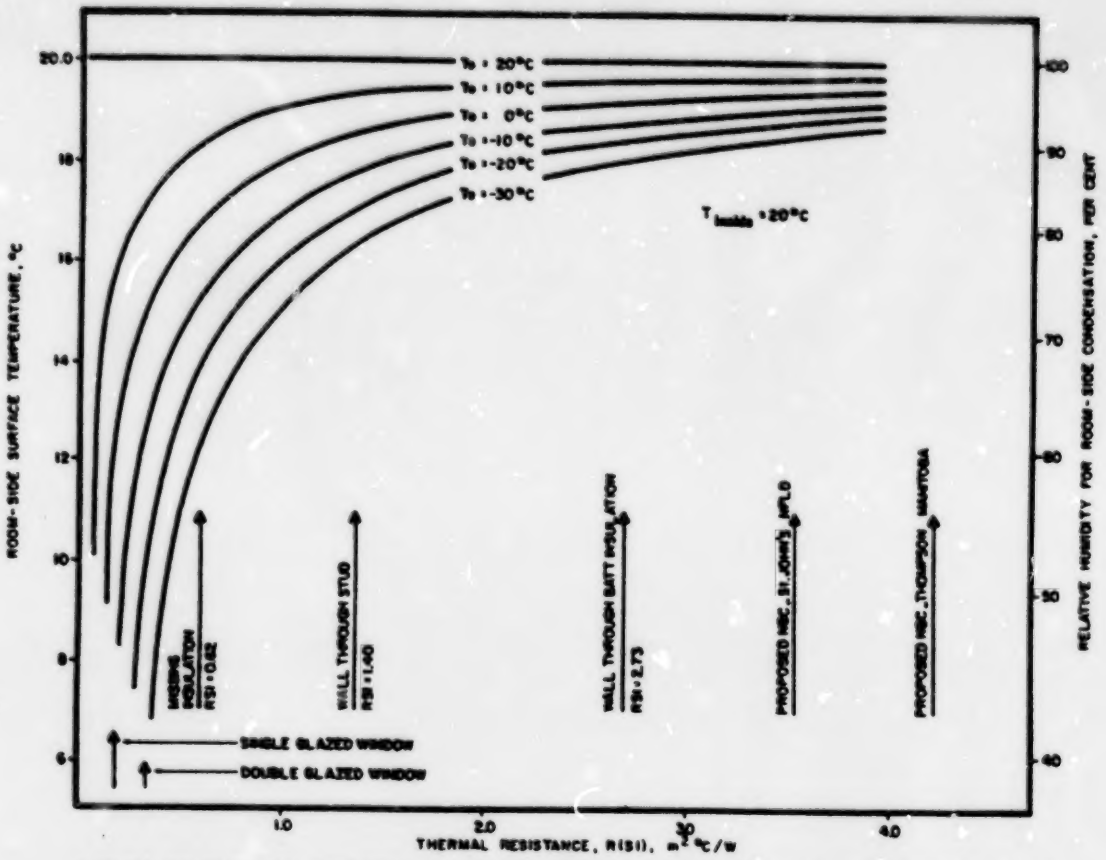
The combination of low wall temperatures and high indoor relative humidity will promote mould and mildew on the inside surfaces of envelope walls. Ontario single family detached and semi-detached homes have the worst ranking in the country for incidence of mould and mildew problems (Table 2).

Problems inside wall cavities are found predominantly in older houses. The lack of an air barrier is thus implicated. Wall cavity moisture will fluctuate with outdoor climate and is especially affected by cold weather. Although high moisture readings have been measured, severe structural damage has not been observed. This suggests enough drying takes place during spring and early summer (April - May). Moisture in wall cavities may also be attributed to rain penetration through openings in the outside sheathing.

Figure 5 shows the likelihood of condensation on interior surfaces increases as:

- thermal resistance of the wall decreases
- outdoor temperature decreases
- indoor relative humidity increases

Theoretically, condensation and discoloration can appear on walls with indoor relative humidity greater than about 60% and outdoor temperature lower than -20°C. Mould and mildew will develop at certain moisture, temperature and air flow conditions. Mould and mildew are discussed in greater detail later in the report.


ROOM-SIDE SURFACE TEMPERATURE, °C
RELATIVE HUMIDITY FOR ROOM-SIDE CONDENSATION, PER CENT
THERMAL RESISTANCE, R(SI), m² °C/W
T_o = 20°C
T_o = 10°C
T_o = 0°C
T_o = -10°C
T_o = -20°C
T_o = -30°C
T_{inside} = 20°C
MISSING INSULATION RSI = 0.62
WALL THROUGH STUD RSI = 1.40
WALL THROUGH BATT INSULATION RSI = 2.73
PROPOSED NBC, ST. JOHN'S, NFLD
PROPOSED NBC, THOMPSON, MANITOBA
SINGLE GLAZED WINDOW
DOUBLE GLAZED WINDOW

A PLOT OF THERMAL RESISTANCE AGAINST ROOM-SIDE SURFACE TEMPERATURE OR ROOM-SIDE RELATIVE HUMIDITY LEADING TO CONDENSATION ON WALLS

FIGURE 5

Source: Marshall, Macklin, Monaghan Ltd., Moisture Induced Problems In NHA Housing, CMHC File 176-04-25. Ottawa, Ontario, June 1983.

An alternate way of reducing wall condensation is increasing the insulation of surfaces to elevate their temperature above the dewpoint. Installing decorative ceiling corner insulation resembling a cornice is an example. Closets with walls to the exterior may not respond to increased insulation. Generally, increasing closet ventilation is recommended to reduce condensation, mould and mildew. Some suggested methods are undercutting the door, adding grilles, leaving the door open or replacing with louvered doors.

Appendix D(ii) outlines a checklist for moisture damage in walls.

4.3 Windows

Incidence of problems in Ontario is comparable to the national average, which is generally low. Condensation is expected (see Figure 5) in single and double glazed windows when indoor relative humidity levels are 30-40%. However, the susceptibility of the occupants to colds is increased at relative humidities below 30%/5/.

Cyclic accumulation and evaporation of condensation on windows is normally acceptable. However persistent condensation will start paint peeling, mould and mildew and, if cold enough, form ice. The insulating value of windows is very low. As for walls, adding to their insulating value is beneficial and can be accomplished by installing storm windows, triple glazing, retrofitting temporary interior storms or replacing with heat mirror windows/12/.

Appendix D(iii) outlines a checklist for excessive window condensation.

4.4 Basements

Waterproofing basements has been a continuing challenge in the field of building technology even before energy conservation and retrofitting. In basements it is important to discriminate between water leaking and high indoor relative humidity. To prevent ingress of water and vapour diffusion, dampproofing basements is best done on the exterior surfaces. Dampproofing or any vapour retarding coating should not cover basement walls above grade to allow a "safety valve" against moisture accumulation. Provisions for exterior sealing are possible in newly constructed homes but not practical in existing homes, unless, for example, repairs to the weeping tile are undertaken. Nonetheless, sealing cracks on the interior is a remedial measure.

Ventilation of basements during hot, humid weather, particularly in late spring and summer, often leads to condensation on cool wall surfaces. The solution is to limit ventilation and instead dehumidify. Conventional home dehumidifiers can achieve a minimum of about 60% relative humidity. An experimental sorbent dehumidifier has been demonstrated to operate effectively at relative humidities down to about 25 to 30%/13/.

Condensation in the joist spaces at the sill plate may rot wood joists. The problem occurs where friction fit batt insulation is pushed into the joist space without a vapour retarder. Here, condensation is primarily caused by vapour diffusion. A major insulation manufacturer is producing fiberglass batt insulation packaged in polyethylene pillows which is intended for the above application/17/. Appendix D(iv) outlines a checklist for moisture damage at the top of foundation walls.

There is no evidence of wall cracking by covering basement walls with insulation/1/.

Water vapour pressure for most of the year is higher in outside soil than in the air in the basement. Wicking of water through basement walls and evaporation can be a large moisture load on a house. Efflorescence (a white, powdery deposit on basement walls) is evidence of moisture wicking and evaporating into the air. Concrete with a high water/cement ratio is quite permeable. Not covering basement walls allows evaporation, on the other hand covering retards or blocks evaporation, causing deterioration of insulation and wood strapping. The solution is to dampproof on the inside surface of the concrete up to grade level and install a vapour retarder on the warm side of the insulation. Measures taken to control entry of moisture are also effective in controlling radon gas ingress.

Basement floors are a specific area of concern. Concrete basement floors alone will not significantly retard moisture diffusion. Investigators recently discovered that moisture emission from basement floors can be a major moisture source/18/. Ground water is usually highest in the late fall and early spring and this may cause water to enter at the footings. Carpeting laid on floor slabs behaves similarly to insulation and lowers slab surface temperature thus increasing condensation build up. Crawl spaces with uncovered soil floors are very large moisture sources. Such floors must be covered

with a vapour retarder such as polyethylene, weighted down with stone or other acceptable material. Ventilation of the space to the outside will help but the crawl space must be "sealed" from the house.

4.5 Mould and Mildew

As defined in ASHRAE/5, p21.19/, mildew is a thin, often whitish growth produced on many surfaces by moulds belonging to the fungi plant group. Moulds that cause mildew flourish whenever it is damp, warm, poorly ventilated or poorly lit. For the purpose of this report, mould and mildew will refer to any moisture induced growth and staining of interior or concealed surfaces of the building envelope.

Three factors combine to cause moulds in residential construction: moisture, temperature, and lack of air movement.

Suitable moisture conditions may result from indoor moisture generation and the outdoor environment (ie, driving rain, high wind exposure, insufficient solar gain for drying). Existing research is not clear if actual condensation is the critical factor producing mould and mildew or whether sustained high relative humidity in the air film next to the wall is critical/2/. Appropriate temperature conditions around the dew point temperature of the indoor air can occur in areas such as thermal bridges, unheated basements, partition walls with leakage paths through the ceiling, and uninsulated exterior walls. Lack of air movement that occurs at ceiling/wall intersections, in attic joist spaces, air space in closets with exterior walls and unventilated crawl spaces also create conditions favourable for mould growth.

The results of a telephone survey of post 1973 NHA Housing with moisture problems/2/ found that, in Ontario, 44 out of 201 investigated cases contained large patches of mould on walls and ceilings. A second national telephone and field survey documented fifty-two cases of moisture problems that could be related to thermal upgrading/1/. Of these, 50% contained evidence of mould and mildew. The results of these two studies suggest that the incidence of mould and mildew is prevalent and not necessarily related to thermal upgrading. Formation of mould and mildew on interior surfaces should remain of some concern especially with respect to health and aesthetic aspects.

Appendix E outlines corrective measure for mould and mildew problems.

4.6 Effects on Wiring

Knob and tube type and NMD type cables were not designed to withstand the combination of moisture and thermal exposures that could be encountered in retrofit, tight and electric converted construction. A report titled "Effects of Thermal Upgrading on Electrical Wiring Systems in Houses"/14/ makes recommendations to investigate the potential problem. Laboratory work is currently being carried out at Ontario Hydro Research.

5.0 CONCLUSIONS

1. The number of reported condensation problems in Ontario problem homes has increased since the mid-seventies. The percentage of houses having condensation problems in Ontario is estimated to be less than 2%. The absolute number of cases may be large (this represents up to about 60,000 of the three million Ontario households).

2. There are no cases of serious problems. The problems that do exist can be solved.

3. The majority of houses having problems are flueless, and indoor relative humidities were found to be above average in the problem houses.

4. The majority of problems appear in the attic and ceiling. Ontario is the province with the highest percentage of mould and mildew cases.

5. Visible condensation which is excessive and persistent is a warning sign.

6. The primary control to reduce visible, and in part, concealed condensation is by reducing source generation.

7. To prevent concealed condensation in top storey ceilings, they should be sealed before adding attic insulation.

8. If homes are conscientiously made very air tight, controlled ventilation will be required.

9. A large gap exists between what is known about condensation and what is practiced.

6.0 RECOMMENDATIONS

6.1 For Marketing

1. If homeowners wish to convert oil heating to 100% electric heating, the chimney should be only temporarily blocked and the home monitored for the appearance of condensation problems for one year before permanent blockage.

2. Homeowners are in the best position to assess the problems in their own homes since the utility advisor can only do a spot check. Therefore educating homeowners is important. Homeowners should inspect the attic one to two years after adding attic insulation in order to check for signs of moisture and ice formation.

3. Check upper parts of the home first when investigating concealed condensation.

4. Distribute the publications listed in Appendix A to homeowners and contractors.

5. Advisors should have sling psychrometers to measure relative humidity in homes.

6. Suggest that homeowners buy inexpensive relative humidity hygrometers to monitor indoor relative humidity.

7. Suggest that homeowners carry out upgrading (sealing, insulation) in stages. Subsequent to each stage of upgrading, the increase of indoor humidity and evidence of visible and concealed condensation should be monitored (requires an educated homeowner).

6.2 For Research

1. Keep abreast of building technology research in Canada and other countries that have a similar climate to Ontario (eg, Sweden).

2. Concentrate further research work on airsealing and controlled ventilation.

3. Field test the practicality of retrofitting a controlled mechanical ventilation system in an existing house. In homes converted to 100% electric heat, investigate the use of chimney as an exhausting vent. Try retrofitting and field testing an exhaust fan at the attic hatch to directly vent humidity outside.

4. Homes undergoing demolition and major renovation will expose concealed condensation damage and air leakage paths. Examine some sample homes to analyze and learn more about concealed condensation.

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APPENDIX A

HOMEOWNER PUBLICATIONS

Canada Mortgage and Housing Corporation (613) 748-2000

- Condensation in the Home: Where, Why and What to Do About It/4/.

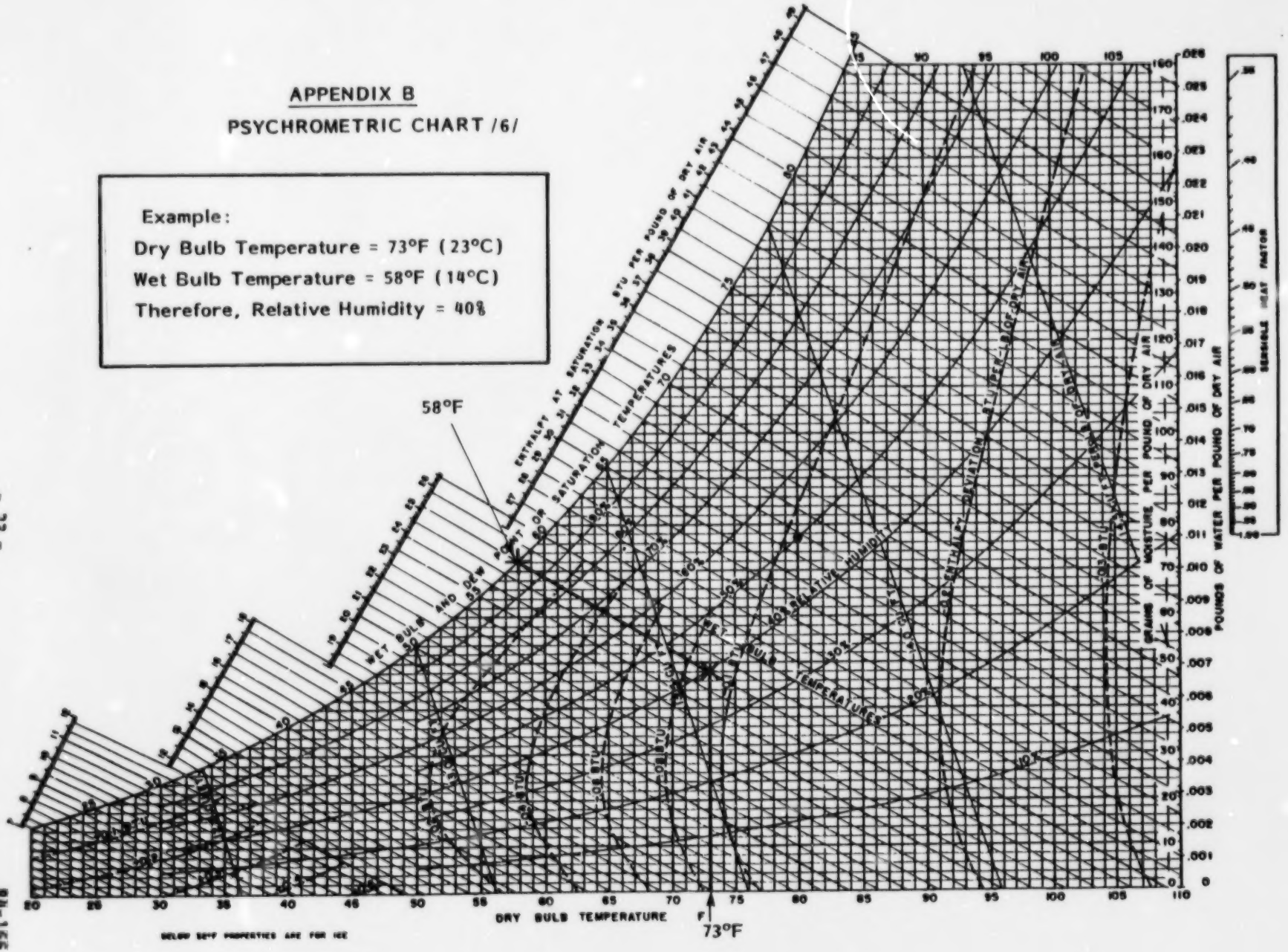
Ministry of Municipal Affairs and Housing (416) 585-6509

- First, Seal Your House
- Fresh Air and Humidity in a Tigher House, More Energy Fact Sheet.
- Air Vapour Barriers, Home Energy Fact Sheet
- Energy Conservation Products, Home Energy Fact Sheet
- Caulking and Weatherstripping, Home Energy Fact Sheet
- Insulating Basements, Home Energy Fact Sheet.
- A Window Review
- Conserve Energy When you Renovate
- Seven Days of Conservation

APPENDIX B

PSYCHROMETRIC CHART /6/

Example:
Dry Bulb Temperature = 73°F (23°C)
Wet Bulb Temperature = 58°F (14°C)
Therefore, Relative Humidity = 40%


58°F
73°F
DRY BULB TEMPERATURE F
WET BULB TEMPERATURES
RELATIVE HUMIDITY
ENTHALPY AT SATURATION BTU PER POUND OF DRY AIR
DEW POINT OR SATURATION TEMPERATURES
GRAINS OF MOISTURE PER POUND OF DRY AIR
POUNDS OF WATER PER POUND OF DRY AIR
SENSIBLE HEAT FACTOR
BELOW DOTTED PROPERTIES ARE FOR ICE

84-1666
165334 RD

APPENDIX C

DIAGNOSTICS FOR MOISTURE MEASUREMENT

1.0 Wood Moisture Meter (Electrical Resistance Technique)/15,1/ "Penetrating resistivity-type moisture probe with insulated pin" can be used to measure the moisture content of the plate, stud and sheathing (surface and interior). This moisture content can be checked against wood chip samples that are wrapped in plastic and later weighed in the lab to determine the moisture content.

2.0 Wood Cores (3/16" dia + 1/4" long) can be taken with a "simple leather punch", stored in plastic straws and refrigerated until lab cultures are performed for decay fungi/1/.

3.0 Relevant items from a 1974 Symposium/16/ are listed below:

3.1 Hedlin, C.P. "The Use of Nuclear Moisture Density Meters to Measure Moisture in Flat Roofing Systems". NMDM Meters (commercial), normally used on soils, were used on flat roofs to identify wet roof areas and estimate moisture presence. The standard error in the field was ± 50 kg/m^3 for moisture contents up to 250 kg/m^3 and ± 100 kg/m^3 for moisture contents up to 400 kg/m^3.

3.2 Green, G.H., Hedlin, C.P., "Measurement of the Humidity of Small Samples of Air Using Gas Liquid Chromatography". Gas Liquid Chromatography can be used to measure humidity by taking samples (including from inaccessible areas) in Teflon-lined, heated syringes. It could be used to measure humidity in inaccessible areas.

3.3 Facaoaru, I., "Non-destructive Methods for Moisture Measurement on Buildings".

3.3.1 Dielectric Constant Method

The method consists of a capacity probe in various configurations (surface, insertion) for testing "soft" materials such as wood, lightweight concrete, plaster. Accuracies of 1-4% are possible.

3.3.2 Microwave Attenuation Method

This method consists of a transmitter and receiver on either side of the test specimen. It is suitable for in-

situ measurement of large surfaces (eg, concrete thickness between 10 to 70 cm). Plane dimensions 1 m x 1 m or larger can be measured to accuracy of about ±4%.

3.3.3 Neutron Methods

A probe detecting H nuclei, as in 3.1, is fixed on the surface and counts all H atoms. Accuracy is ±4% for neutron counting time of one minute for "field of usual humidities".

3.3.4 Magnetic Nuclear Resonance Method

The method is laboratory based, has high accuracy but the equipment is expensive.

3.3.5 Ultrasonic Pulse Method

Moisture content is measured as a function of ultrasonic pulse velocity. The method is rapid, simple, has accuracy of ±4-6% and might be used to follow changes in moisture content. It requires a reference measurement on dry wall and a calibration curve of the humidity-velocity relationship for the tested material.

APPENDIX D
CHECK LISTS

Source: Marbek Resource Consultants, Handbook on Air Sealing Homes for Energy Conservation, PRELIMINARY EDITION ONLY, Energy, Mines and Resources, Canada, Ottawa, Ontario, 1984.

(i) Is there moisture damage in the attic or roof space?

SYMPTOMS

- Discolouration of the ceiling finish
- Sag of the ceiling plasterboard, with nail pull-off or rusting around nail heads
- Discolouration of roof sheathing, or water marks on the roof framing members
- In winter: frost or condensation on the sheathing and framing members
- Signs of water damage on insulation.

CAUSES

- Rainwater penetration due to defective roof materials or installation, and/or
- The exfiltration of humid house air into the attic/roof space. Note that the level of ventilation provided in the attic/roof space influences the likelihood of problems due to exfiltration. In some instances there may be excessive exfiltration air leakage into the space, but if there is adequate ventilation there may be no serious moisture damage.

RECOMMENDED ACTION

- Determine whether the problem is caused by exfiltration or rain penetration. Note that in some cases the signs of moisture damage may be very old, and may be due to rainwater leakage through a defective roof covering several years previously. In such cases, the contractor can benefit from the knowledge of the householder regarding past repair work.
- If the symptoms are due to exfiltration, determine whether or not the roof or attic cavity is adequately ventilated. Is there adequate ventilation at soffits, gables, roof slope, etc? Have the ventilation channels been blocked by insulation? In winter, are the vents blocked by ice? If the ventilation is inadequate, improvements should be made.
- Generally, where moisture damage occurs in an attic or roof space as the result of exfiltration, a high priority should be assigned to the sealing of air leakage points in the ceiling.

D(ii) Is there moisture damage in the walls?

SYMPTOMS
• Bubbled paint on the exterior siding • Odour in the house • Discolouration or fungus growth on the interior finished surface of the walls. • Rust on drywall nails • Signs of corrosion inside electrical outlets in exterior walls • Mildew and dampness.
CAUSES
• The exfiltration of humid house air into the walls through various air leakage points, and/or • Rain penetration through the exterior siding.
RECOMMENDED ACTION
• Determine whether the problem is caused by exfiltration or by rain penetration, taking account of local climatic conditions and existing structural problems. • If the symptoms are due to exfiltration then the sealing of air leakage points in the exterior walls will save energy <u>and</u> reduce the moisture damage problem.

D(iii) Is there excessive condensation on windows?

SYMPTOMS

- Water damage of the window frame, particularly on the sill
- Water damage on the wall finish around the window unit
- In winter, large accumulations of frost or condensation on the window panes.

CAUSES

- Excessive humidity levels in the house and/or inadequate thermal resistance of the windows
- In multi-layer windows, such as double or triple slider units, signs of condensation between the various layers of glass are an indication of air exfiltration.

RECOMMENDED ACTION

- Determine whether the problems are caused by excessive humidity levels in the house, by poor thermal resistance of the window units, by air exfiltration, or by combinations of these.
- If the problem is caused by excessive humidity generation in the house, proceed with caution when selecting a sealing package. Any sealing work will tend to decrease the air movement through the house, and this will lead to higher humidity levels. In turn, these could create a range of moisture damage problems. (Some obvious signs of excessive humidity generation are the need for one or more dehumidifiers; the venting of dryers into the house; large families with several small children; large numbers of house plants.
- If the problem is caused by poor thermal resistance of the window (single pane, poor outer storm, etc) it is advisable to upgrade the window.
- If the problem is caused by air exfltration in multi-pane windows, improved weatherstripping should be installed.

D(iv) Is there moisture damage at the top of foundation walls?

SYMPTOMS

- Discolouration of the wood structure where it joins the top of the foundation wall
- In winter, condensation or frost build-up on the wood frame at the top of the foundation wall
- Dry rot, fungus, or mildew on the wood frame.

CAUSES

- The most likely cause is moisture movement through the foundation wall, by "wicking". The effect tends to be stronger in foundation walls that have mortar in their construction, such as concrete block or stone walls.

RECOMMENDED ACTION

- When this problem is encountered, it is generally inadvisable to seal the area at the top of the foundation wall. There are two reasons:
  - First, it is unlikely that a good seal could be maintained around the defective woodwork; second, the air leakage at this point helps to control excessive moisture build-up. Because sealing will tend to reduce the air leakage, it could cause accelerated moisture damage.
- In general, proceed with caution. It is recommended that contractors draw the attention of the householder to the problem and explain that remedial measures should be conducted before sealing.

APPENDIX E

POSSIBLE CORRECTIVE MEASURES FOR MOULD AND MILDEW

Following is a list of possible corrective measures to control and reduce the incidence of mould growths:

Existing Construction

1. Interior Surfaces - Walls, Ceiling

(a) Eliminate or reduce moisture sources to a maximum of 45% relative humidity by the following measures:

- Use kitchen, bathroom, etc exhaust fans to ventilate
- Turn off humidifiers
- Vent dryers outside
- Operate the furnace circulating fan if a return air register is available in the affected area
- Leave window(s) in the affected area open until clear of localized condensation
- Ensure there is a watertight membrane on a crawl space floor.

(b) Clean infected area with mould growth retardant*. Apply the retardant with a brush or damp sponge, wipe and allow the surface to dry thoroughly.

(c) Alternative approaches are listed below:

- Remedy less severe stains with oil-based paint followed by a second coat of desired colour.

- Add a small amount of preformed insulation to raise the temperature of the affected area above the dewpoint; provide a fire resistive surface finish and secure with adhesive to prevent condensation behind the insulation.

- Increase air movement in poorly ventilated spaces (ie, closets with exterior walls) and add insulation on exterior walls to raise the temperature above the dewpoint.

  A possible approach is outlined in Reference 2.

- If exterior siding requires replacement, retrofit with vapour permeable air barrier (eg TYVEK a recently developed product) and insulated sheathing.

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* 3L Water, 1 L Javex, 75 mL trisodium phosphate, 25 mL detergent, 1 tsp all purpose liquid cleaner

2. Interior Surfaces - Window and Door Frames

(a) As in 1(a) and 1(b).

(b) Alternative approaches include:

- Adding plastic or glass panes to increase thermal resistance.
- Installing storm windows and doors.
- Caulking around window and door frames to reduce local air infiltration and condensation potential.

3. Concealed Attic Spaces

(a) Improve air barrier (ie, seal interior partitions, light fixtures, plumbing stacks, electrical penetrations with caulking and polyethylene film).

(b) Ensure attic vents are unobstructed.

(c) Increase attic ventilation.

(d) Decrease relative humidity in the living space.

New Construction

1. Interior Surfaces - Walls

- Reduce the extent of cold areas, and potential wall staining by improving the integrity of the inside vapour retarder, minimizing the amount of thermal bridging and applying insulated sheathing and a vapour permeable air barrier to exterior walls.

2. Interior Surfaces - Window and Door Frames

- Triple glazing may be used to reduce surface condensation and subsequent run-off into the frames.
- Careful sealing and insulation of frames will reduce thermal bridging and localized air leakage.

3. Concealed Attic Spaces

- Improve the vapour retarder integrity between insulation and ceiling.
- Add vapour permeable air barrier over insulation.
- Ensure adequate attic ventilation.